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Research Article

The effect of using STEM education on students' mathematics achievement

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Science, technology, engineering, and mathematics (STEM) education has emerged as a powerful tool for boosting students' mathematics achievement. By integrating these disciplines, students are equipped with essential skills for the 21st-century workforce and can develop a deeper understanding of mathematical concepts. Through hands-on experiments, problem-solving activities, and real-life applications, STEM education offers a dynamic approach to learning mathematics. This quasi-experimental study aimed to investigate the impact of STEM education on mathematics achievement among 8th-grade students. Although the study lacked the full randomization typically seen in experimental designs, it meticulously designed and validated its measurement tool for assessing mathematics achievement. The pre-and post-tests administered to both the experimental and control groups provided valuable data for evaluating the effectiveness of the STEM education intervention. The statistically significant difference in mathematics achievement between the two groups, with a significance level of ≤ 0.05, strongly suggests that the STEM education program had a positive and meaningful impact on the experimental group's math skills. As a result, the study offers valuable insights into the potential benefits of integrating STEM education into the curriculum for middle school students. Students are encouraged to think critically, collaborate with their peers, and utilize their creativity to solve complex problems. This interdisciplinary approach fosters a deeper engagement with the subject and ignites a passion for learning.

Keywords: Student achievement; Mathematics education; STEM; Training

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1. Introduction

Mathematics provides the necessary tools and language to explore scientific phenomena, analyze data, and design technological solutions. Without a solid understanding of mathematics, students would struggle to grasp the complexities of science, technology, and engineering. In STEM education, mathematics is not taught in isolation but is integrated into real-world contexts. Students learn to apply mathematical concepts and principles to solve practical problems. This application-based approach makes mathematics more meaningful and relevant, as students can see its direct impact on their lives and the world around them. This experiential learning approach allows students to see the relevance of mathematics in their everyday lives, making it more enjoyable and meaningful (León et al., 2015; Ryan, 2021). Moreover, STEM education promotes critical thinking skills, which are vital for success in mathematics. STEM education provides students with opportunities to develop and apply critical thinking skills in the context of

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mathematics. Additionally, STEM education promotes higher-order thinking skills, such as problem-solving, creativity, and innovation (Gürsoy et al., 2023). These skills are essential for tackling complex mathematical problems that require students to think outside the box and come up with innovative solutions. Technology also enables personalized learning experiences in mathematics. With adaptive learning platforms and online resources, students can engage in self-paced learning, receive immediate feedback, and access additional support materials. This personalized approach allows students to learn at their own pace, fill gaps in their understanding, and challenge themselves with more advanced concepts. Furthermore, technology provides students with opportunities for collaborative learning and global connections (Sileyew, 2019). It is important for educators to leverage technology effectively in STEM education to enhance mathematics learning. By integrating technology into the classroom (Azennoud, 2023), teachers can create engaging and interactive learning experiences that inspire students to explore and excel in mathematics (Engin, 2023; Gürsoy et al., 2023).

A growing body of research highlighting the benefits of incorporating STEM principles into mathematics instruction is highlighted in the literature that is now available on the relationship between STEM education and mathematical achievement (Seage & Türegün, 2020). Several studies have found that incorporating STEM concepts into the classroom enhances students' math abilities. First, research shows that STEM training improves mathematical understanding by providing practical applications and hands-on experiences. Mathematical learning includes the acquisition of analytical, problem-solving, and logic skills in children, all of which STEM activities foster. Another benefit of STEM education is that it encourages interdisciplinary learning, enabling students to make links between mathematics and other STEM areas (Craig & Marshall, 2019). This combination leads to higher degrees of performance by boosting students' abilities to apply mathematical principles in real-world circumstances.

The research also emphasizes how crucial student motivation and engagement are to mathematics proficiency in STEM fields. In addition to increasing students' interest in and enjoyment of mathematics, active participation in project-oriented or inquiry-based learning experiences also encourages greater conceptual comprehension and long-term memory of information. Studies have also examined teacher professional development's impact on implementing STEM methods for math instruction (Macun & Cemalettin, 2022). Teachers who have received training in STEM curriculum and instructional development are better able to develop stimulating learning settings that encourage mathematical thinking and problem-solving abilities. Recognizing the gaps in the literature is crucial, though. Further research is required to determine the long-term benefits of STEM education on mathematical achievement and the influence of specific instructional methodologies, assessment techniques, and contextual variables.

STEM education is undeniably a holistic and forward-thinking approach to education in the 21st century. It promotes an interdisciplinary mindset, helping students recognize the interconnectedness of STEM in real-world applications. Incorporating practical examples, not only enhances students' motivation to learn but also equips them with the skills needed to navigate global challenges and adapt to evolving conditions. This foundational skill set is applicable across all grade levels and professions, making it invaluable. Moreover, STEM education fosters scientific creativity, global competitiveness, and a spirit of entrepreneurship and innovation (Landolfi, 2023). It also emphasizes the importance of cultural and democratic values, contributing to the development of responsible and well-rounded individuals. Recognizing the intersection of STEM fields with business and industry further underscores its relevance in the modern world. In essence, STEM education empowers individuals to excel in a complex and interconnected global landscape, where adaptability and innovation are paramount.

Even though mathematical aptitude is considered extremely important and highly valued by parents and teachers, it is common practice to undervalue children's motivation in education. When teachers always utilize an ineffective lecture structure in their lessons and seek to teach all of the knowledge in their textbooks, it might be difficult for students to develop a genuine interest in mathematics education. Children frequently lose interest in math classes due to the monotonous, repetitive teaching method and the excessive emphasis placed on remembering facts and learning skills (Cahapay & Labrador, 2022). The following list provides an overview of the main conclusions, theories, and frameworks around the connection between mathematics achievement and STEM education.

STEM education has not been extensively studied in children as young as three, but there is evidence that it is beneficial to them in other project-based learning modules. When one examines the study that has been carried out on STEM education, it becomes abundantly evident that many academics have acknowledged the demands above and conducted a great deal of research on the subject. Some of these studies investigated whether or not there was a correlation between the amount of time students spent participating in STEM activities and their overall academic achievement (e.g. Wanf & Li, 2023). Some researchers conducted meta-analyses, which allowed the impact of some moderators to be measured (e.g. Belland et al., 2017; Santhosh et al., 2023). In addition, studies indicated that children of preschool age could enhance their knowledge of STEM subjects when provided with specialized support in the form of well-designed, engaging, and developmentally appropriate activities (Brenneman et al., 2019). Incorporating STEM activities into a child's pre-kindergarten curriculum is beneficial, as educators and parents widely recognize it. In the end, STEM education is a different method of approaching schooling. There is a certain amount of information on the effects of STEM learning across all age groups (Osman & Saat, 2014); however, this understanding is limited, and most of the studies are still in the conceptual, speculative, and curriculum design stage. The majority of research examining the effects of STEM education has focused on the influence that it has had on the academic performance of students and their attitudes towards the process of learning (Eroğlu & Bektaş, 2022; Shahbazloo & Mirzaie, 2023). Other topics, such as idea analysis (Karakaya & Yılmaz, 2022; Mumcu et al., 2022), curriculum research (Akyea & Radakovic, 2023), teaching techniques, and implementation cases, have garnered attention (Roehrig et al., 2012). As a direct consequence, there is a lack of evidence regarding the efficacy of STEM education in the classroom.

The literature emphasizes the value of student motivation and engagement in STEM activities for raising math achievement. Furthermore, the research underlines the need for teacher professional development in applying successful STEM practices for mathematics instruction. Teachers who receive STEM pedagogy training and assistance are better able to develop stimulating learning environments and encourage mathematical thinking.

The specific objectives of this research are:

1. To evaluate the effect of integrating STEM education in mathematics instruction on learners' overall mathematics achievement.
2. To investigate the branches of mathematics (such as problem-solving, critical analysis, and algebraic reasoning) that benefit from STEM education.
3. To look into how kids' desire and involvement in STEM activities affect how well they do in arithmetic.
4. To investigate any potential differences in the impact of STEM education on students' math achievement that may be related to diversity or gender.

2. Method

2.1. Research Design and Participants

A quasi-experimental research design has been used for this investigation. Without utilizing randomization to assign participants to the control and treatment groups, the quasi-experimental approach enables the exploration of causal correlations between variables. Due to practical limitations and the necessity to investigate the impact of integrating STEM education on students' mathematics success within a particular educational context, this approach was adopted. The experimental group, which receives STEM-integrated mathematics training, and the control team, which receives conventional math instruction without STEM integration, comprise the study's two groups (Hassan Majeed et al., 2021). The pre-test was completed to determine baseline math proficiency levels before implementing the STEM integration intervention. After a set amount of time had passed after the STEM-integrated mathematics education had been executed, the post-test was given. The groups were attempted to be matched based on demographic traits, prior mathematics achievement, and teacher qualities to assure the comparability of the groups. Relevant characteristics, such as the student's socioeconomic background and initial math self-efficacy, were also included in the study. The study involved 52 participants, with 26 students placed in the experimental group for the analysis and 26 positioned in the control group. Every participant completed the survey, yielding a one hundred percent response rate.

2.2. Variables and Data Collection

The study's independent variable is adding STEM education to math instruction. The teaching strategy is being manipulated, with students in the experimental group receiving standard mathematics instruction without STEM integration, whereas students in the control group receive the former. The dependent variable is the pupils' math achievement, which evaluates their skill level or competence in math. It is considered using pre- and post-tests that assess pupils' mathematical skills, competence, comprehension, problem-solving ability, and overall mathematical success. The objective is to determine whether STEM education integration, as opposed to conventional mathematics instruction, significantly affects students' mathematical achievement. The study may incorporate controlling variables, often known as covariates, to account for potential confusion. These covariates, which may affect students' mathematical achievement and need to be maintained in the study to isolate the precise impact of STEM education integration, include students' socioeconomic status, past mathematics achievement, and teacher credentials.

This study used standardized tests as the measurement tool to evaluate math proficiency. The standardized assessments were carefully chosen to match the curriculum and learning goals of the student's mathematical instruction. These exams thoroughly evaluated students' mathematical achievement because they covered various mathematical concepts, problem-solving techniques, and critical thinking skills. The study used performance-based assessments and standardized testing to examine how well students applied mathematical ideas in authentic settings. Students had to complete problems for these examinations that involved problem-solving, logical thinking, and mathematical modelling.

The survey used for this research was a questionnaire comprising several items. Using Cronbach's Alpha coefficient, the reliability and internal consistency of the questionnaire were evaluated, yielding a value of = 0.85. There were 6 questions in the survey assessed students' opinions and experiences in mathematics classes, particularly concerning how STEM education affected math achievement.

2.3. Data Analysis

To compare the arithmetic proficiency of both control and experimental groups, the quantitative results from the pre-and post-tests were investigated using applicable statistical procedures such as random sample t-tests or analysis of covariance (Sileyew, 2019).

Statistical approaches were applied to assess the quantitative information from tests and surveys. Descriptive statistics such as means and frequencies were produced to summarize survey responses (Stier et al., 2020). The study employed a comprehensive statistical analysis, including dependent *t*-tests for within-group comparisons (pre-test to post-test) and independent t-tests for between-group comparisons (post-test scores of the experimental and control groups).

3. Results

The findings of the research point to the benefit of STEM education for pupils' achievement in mathematics, as illustrated below. The data analysis showed substantial differences between the group participating in the experiment, which received STEM-integrated mathematics training, and the control group, which received conventional mathematics instruction. Table 1 presents the descriptive statistics of the groups.

Table 1
Descriptive statistics of experimental and control groups

Group	*Pre-test mean score*	*Post-test mean score*	*Difference*
Experimental	75.2	83.6	+8.4
Control	73.8	76.2	+2.4

The results of this experimental study investigated the impact of incorporating STEM education on students' mathematics achievement showed that the experimental group had an average score of 75.2 on the pre-test, and the comparison (control) group had an average score of 73.8 on the pre-test. After the intervention, the experimental group improved significantly, with an average post-test score of 83.6. The control group also improved but to a lesser extent, with an average post-test score of 76.2. A dependent sample *t*-test was conducted to test the significance of the differences between pre- and post-tests.

Table 2
Dependent t-test results between the pre- and post-tests

Comparison	*df*	*t*	*p*
Within the experimental group	25	8.72	< .05
Within the control group	25	2.35	< .05

Within the Experimental Group, a dependent t-test revealed a statistically significant improvement from pre-test to post-test, with a mean increase of 8.4 points ($t(25) = 8.72$, $p < .05$). Similarly, within the Control Group, the dependent t-test indicated a significant enhancement from pre-test to post-test, with a mean increase of 2.4 points ($t(25) = 2.35$, $p < .05$).

Independent samples t-test was also conducted to test the significance between the scores of experimental and control groups. Table 3 presents the test results.

Table 3
Independent sample t-test results between the post-tests

Comparison	*df*	*t*	*p*
Experimental vs Control (Post-test)	50	4.81	< .05

An independent t-test between the post-test scores of the Experimental and Control Groups demonstrated a statistically significant difference, confirming the impact of STEM education on students' mathematics achievement ($t(50) = 4.81$, $p < .05$). This indicates that the difference in scores between the two groups is unlikely to have occurred by chance. The Experimental Group exhibited a post-test mean of 83.6, while the Control Group displayed a mean of 76.2.

4. Discussion

The study concludes that incorporating STEM education has a positive impact on students' mathematics achievement. The significant difference in mean scores suggests that this improvement is not due to random chance. In addition to quantitative results, the study also includes qualitative findings. These qualitative findings are based on survey responses and participant observations. The experimental group's students were reported to show better motivation, engagement, and critical thinking levels during arithmetic lessons. They also demonstrated a better understanding of mathematical concepts and the ability to apply them in practical situations (Nanjundeswaraswamy & Divakar, 2021). It represents the evidence that incorporating STEM education has a statistically significant positive impact on students' mathematics achievement. The qualitative findings further support this by highlighting improvements in motivation, engagement, critical thinking, and practical application of mathematical concepts among the experimental group.

STEM programs prioritize critical thinking and practical knowledge, preparing learners to face the challenges of the twenty-first century. This implies that STEM education goes beyond rote memorization and encourages students to apply what they learn in real-life situations. This type of education encourages the creation of creative projects within STEM domains (Nağaç et al., 2021). The hands-on approach allows students to apply their knowledge and problem-solving skills in innovative ways. By equipping students with STEM skills, they are better prepared to enter the workforce and contribute to industries that rely on science and technology. It aims to foster scientific literacy among students. Numerous studies have repeatedly demonstrated that incorporating STEM education into mathematics instruction improves kids' arithmetic proficiency. Students who participate in STEM activities show enhanced problem-solving skills, the capacity for critical thought, and a more robust conceptual grasp of mathematical ideas. Constructivism, which prioritizes active learning and practical experiences, and the socio-cultural theory, which emphasizes the value of social interactions and collaborative learning in mathematics instruction, are two theoretical frameworks that support the beneficial effects of STEM education on math achievement (Crabtree et al., 2019). These frameworks support learner-centered and inquiry-based teaching methods, which align with the tenets of STEM education. This means not only imparting subject-specific knowledge but also teaching students how to think critically and apply scientific principles to various situations (Fufa et al., 2023).

The study emphasizes inquiry-based, practical instruction and the value of group projects and interpersonal interactions in math education and the study mentioned in this paper did not find any unexpected or contradicting results. Instead, it consistently demonstrated the positive impact of integrating STEM instruction on math achievement. This paper also suggests that future research could explore potential variations in the effectiveness of STEM integration across different student groups or educational settings (Gnagey et al., 2016). This would help further refine our understanding of the impact of STEM education. Many previous studies that have been done on the positive impact of Science, Technology, Engineering, and Mathematics (STEM) programs on student achievement, attitude, interest, communication skills and problem-solving has alerted the education community to reform instructional approaches in STEM subjects (Han et al., 2015; Kazu et al., 2021). Also incorporating STEM education into mathematics instruction suggests that further research can provide insights into its broader impact.

5. Limitations and Challenges

The study's limitations reveal several critical concerns that warrant careful consideration. The reliance on a small sample size of just two classrooms through convenience sampling compromises the study's ability to generalize findings to a broader population. The absence of random assignment further impedes the establishment of causal relationships and introduces the risk of selection biases. Additionally, the use of self-reported surveys, while common, introduces the potential for response biases, potentially affecting the internal validity of the study. Collectively, these limitations cast a shadow over the study's external validity, limiting the extent to which its findings can be applied beyond its specific context. Recognizing and addressing these limitations in the study report is crucial for transparency and for helping readers assess the study's generalizability and implications accurately. It should heed these limitations when interpreting the results and use them as valuable insights for designing future studies that strive for more robust and widely applicable research outcomes.

6. Practical Implications and Recommendations

The research suggests that teachers can benefit from implementing experiential learning approaches in the classroom. Experiential learning involves hands-on activities and real-world applications of mathematical concepts. Teachers can enhance comprehension and engagement in mathematics by providing students with opportunities to apply mathematical knowledge in practical situations. Project-based instruction is another effective strategy highlighted in the study. This approach encourages students to work on projects and solve real-world problems that require mathematical skills. Students can develop a deeper understanding of mathematical concepts and their practical relevance by engaging in project-based activities. Collaborative problem-solving activities are recommended to promote student engagement and comprehension in mathematics. These activities encourage students to work together to solve complex problems, fostering teamwork and critical thinking skills. Practitioners should aim to create a warm, supportive, and encouraging learning environment that fosters students' inquisitiveness, creative expression, and analytical reasoning. A positive classroom atmosphere can enhance student motivation and learning outcomes. The research recommends adopting a comprehensive strategy for implementing STEM education. This strategy should prioritize experiential learning opportunities that allow students to connect mathematical concepts with practical applications. It should encompass a holistic approach to STEM education, emphasizing the integration of STEM subjects and real-world relevance.

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